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ATMOSPHERIC TRANSPORT OF PESTICIDE AEROSOLS

John W. Scotton

Public Health Service
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Atmospheric Transport of Pesticide Aerosols

John W. Scotton, Meteorologist

JULY 26, 1965

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
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FOREWORD

There are about 60,000 chemical pesticide formulations on the United States market today and the volume used is steadily growing. Agricultural chemicals constitute by far the largest portion of the pesticides volume in use.

Government officials and the general public are increasingly concerned with the proper uses, controls and applications of pesticides. Registration, research and monitoring programs have been and are being implemented in the federal and state governments to insure the most appropriate use of effective pesticides. These programs were created to help maintain and improve our food supply, and to control disease-bearing insect pests and unwanted weeds. At the same time, the health of man and other life must be protected against the toxic effects of improperly used pesticides.

Information and data on the atmospheric transport and diffusion, wind drift and meteorological effects on pesticides and their application is herein presented. The relative size of pesticide aerosols, application techniques, equipment employed, and weather effects on insects and crops is discussed, as is the role of the U.S. Weather Bureau and the agricultural meteorologist.

The effect of weather parameters on the use, application, effectiveness and decomposition of pesticides is an important consideration in agricultural production and in the food chain. Meteorology and climatology must also be considered in the protection of the health of man and animals from the toxic effects of pesticides.

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ATMOSPHERIC TRANSPORT OF PESTICIDE AEROSOLS

I The Pesticides Controversy

Pesticides are chemical substances which are used to kill pests such as insects, rats, weeds, algae, nematodes (worms), and other destructive forms of life. There is no doubt that the records show that the manifold uses of pesticides in the United States and in the world, since World War II particularly, have improved man's lot. The proper use of pesticides has helped insure a greater abundance of food, has reduced crop damage from insects and weeds, and has helped the control of disease-bearing insects such as mosquitos, flies, roaches, etc. Pesticides use is now a major consideration in agriculture, just as is fertilization, irrigation and other soil use practices. Production in the United States alone increased in two decades from 150,000 tons in 1941 to 410,000 tons in 1961. Approximately one-third of this production is exported to other countries. The remarkable record of pest control in agricultural production throughout the world has been matched by the efficacy of pesticides control of pest-vectored scourges of a wide spectrum of diseases such as malaria, yellow fever, bubonic plague, encephalitis, typhus, etc.

A Some Relevant Literature

While there is no argument that the world has benefited greatly in the last two decades from the use of chemical pesticides, the rapidly expanding and insufficiently controlled use of some of these pesticides, such as the chlorinated hydrocarbons and the organic phosphorus insecticides, is creating a real and potential hazard to the health of wild life and man. Rachel Carson's book "Silent Spring", which was well-documented but probably over-zealous, did the world a service in bringing into sharper focus the need for scientific research to determine the acute and chronic effects of pesticides on animals and man in the environment.

The increased use of and interest in pesticides since World War II has resulted in a large volume of published reports on pesticide research. Some of the articles, in addition to Rachel Carson's book, describing the broad implications of pesticides, include:

(1) "Pesticides: A Contribution to Agriculture and Nutrition" by Dr. W. J. Darby, states: "In 1940, it was estimated that the labor of one farmer produced food and fiber sufficient for about 11 persons; today, he provides enough for from 26 to 29 individuals. . .a part of this revolution has been the intense, concentrated, scientific form of agricultural crop management. This makes for efficiency, but at the same time, makes crop land more susceptible to losses due to unexpected or uncontrolled epidemics and plant diseases or is occasioned by uncontrolled animal pests."

(2) "Pesticides: The Challenge, How Do We Meet It?", written by Dr. H. L. Haller, states: "What are pesticides doing to the atmosphere around us?. . . .I believe that the U.S. Public Health Service does not consider airborn pesticides a community-wide public health problem. Unlike other air pollutants, pesticides are formulated to settle rapidly and not to spread widely over a community." Incidentally, not everyone in the U.S. Public Health Service nor the U.S. Weather Bureau agrees with Dr. Haller's statement.

There have been many examples of poorly controlled spraying or dusting applications where the toxic residues have left hazardous levels of pesticides on crops or in bodies of water which have affected wildlife and our food supplies to an extent which is considered hazardous to health.

(3) "Pesticides: A hazard to Nature's Equilibrium", by Dr. L. P. Cole, states: "Man is doing many things that thoughtful biologists find disturbing; the widespread use of pesticides is only one of these. . . . studies of the ecology of potential pests species and the species to be protected could pay big dividends. The casual exterminator would neither notice nor recognize the significance of the fact that in parts of California, while parasites fail to control the purple scale insect, 90% of these pests are confined by micrometeorological conditions to the northern halves of the trees. Thus, there is present a chance for selective treatment to eliminate the bulk of the pest population with a minimum risk of destroying community diversity through broadcast exterminating procedures."

(4) "Pesticides in our Ecosystem", in 1964, by Egler believes that ecology should include the study of the entire ecosystem. The "Eco" should not mean environment of or something around something else, but should mean the totality of a site or habitat and everything in it. In meteorology, an individual low pressure system has been studied as a separate entity, but since it is a part of the general circulation, it must be studied in this perspective. By analogy, pesticides cannot be separated from the environment, but must be studied as a part of a totality.

B U. S. Administration Policy

On May 15, 1963 the President's Science Advisory Committee issued a report on the Use of Pesticides. In that report benefits from the use of pesticides and the hazards of using pesticides are both recognized. As a result of this study, greatly increased programs of research on the toxicity of pesticides, pesticide residue analysis, and pest control without chemicals were instituted in the United States. The Fifth International Pesticide Congress, held in London in 1964 also emphasized that more specific detailed data is the big need in pesticide research.

C Legislation

Federal and state pesticide legislation is being reviewed and rewritten for improved control, and the Departments of Agriculture, Interior, and Health, Education and Welfare have been directed to pursue every facet of activity necessary to improve the use and control of pesticides.

II Chemical Drift Problems

A Hazards

A fundamental problem of chemical drift is the hazard caused to people, animals, wild life and crops adjacent to the chemical application areas. The problem is compounded subtly when feed crops which receive chemical residues not intended for them such as alfalfa and corn are fed to animals, thus causing residues in meat or milk. The efficiency utilized in applying the pesticide chemical, or, too frequently, careless applications result in degrees of drift which are more pronounced and create more problems than the contamination, which is a factor to be reckoned with even when chemicals are properly applied. It is very

important, therefore, that greater research and efforts are made in the direction of improving efficiency in applications, which will result in lower dosages, reducing drift hazards as well as proving to be economical to the applicators.

It is virtually impossible to eliminate entirely drift of agricultural chemicals, whether applied from the ground or aircraft. Tracers used in air pollution studies have drifted up to 22 miles, and greater distances may be recorded with more accurate means of sensing the tracer chemicals.

B FDA Miller Amendment and Other Statutes for Setting Tolerances

The Miller Amendment to the Food, Drug, and Cosmetics Act passed by the 1954 Federal Congress provides that chemical residue tolerances will be allowed for specified chemicals on specific crops, with zero tolerance applying to all unspecified cases. Since milk and milk products have no chemical tolerances granted, zero applies. The Delaney Amendment specified zero tolerances for any known carcinogenic chemical. California, which uses 20% of the agricultural chemicals used in the United States, has been one of the most progressive and forward-looking states in passing pesticide legislation. It has had an agricultural chemicals residue law since 1927, and is one of the few states to have one. To prevent conflict with the Federal law, California adopted in August, 1960 the Federal standards specified in the Miller Amendment. One notable exception was a C.5 ppm (parts per million) tolerance of DDT on produce to be used as dairy feed, where under Federal law a zero tolerance prevails. However, residue analysis techniques and instrumentation have greatly increased residue detection sensitivity and it is likely that this tolerance exception may have to be reduced. For practical considerations, and when more has been learned about the possibility of allowing small tolerances of certain materials in milk where the zero tolerance presently applies, these may be revised to allow very limited parts per million of such residues.

C Dusts

Even though, in the past, dust formulations have been quite popular with aircraft operators and applicators, the use of dusts has declined rapidly during the past several years for two good reasons:

(1) The control residue deposit on a plant is only 1/3 to 1/4 that of a comparable spray application when both are applied by aircraft.

(2) The drift from dust applications shows from 5 to over 100 times more drift residue than sprays that point downwind from the applications site, the difference increasing with the distance (100 ft. to 1/2 mile) from the aircraft flight pattern.

Even though dusts repeatedly show less in actual deposit and more downwind drift than sprays, their use persists because they have greater effectiveness in certain insect control programs. There is also less labor involved in the handling and applying of dusts, since no formulating is required at the application site. Agricultural dusts consist of particles with a size range of roughly 0.1 to 25 microns and an arithmetic average size of about 5 to 10 microns. These very fine particulates, averaging from 20 to 30 times smaller than a fine spray, will penetrate plant foliage and will deposit on the backside of leaves whereas larger spray particles will not. There is also some evidence that some pesticides are toxicologically more effective as fine-particle dusts than as sprays.

D Granulars

The extreme opposite of fine dust formulations would be the granular materials. These particles range in size from 600 to 200 microns for the usual 30 to 60 mesh size range. These large particles obviously produce less drift hazard, but their size will not permit sticking to plant surfaces, and their small numbers per unit of volume will not give sufficient coverage for many pest problems.

E Sprays

Sprays are by far the most universal and versatile application. A spray formulation may have a water or oil base, may be an emulsion where the active chemical is usually in the oil, or it may be in wettable powder form with the active chemical on a suspended clay particle. The physical factors of viscosity, density, and surface tension, influence spray particle size, but these do not vary greatly in usual formulations. Size is mostly controlled by the type of atomizer, its design and operation. The atomization devices in commercial agricultural use produce particles ranging in size from a probable 1 micron to 400 or more. For this reason, the particle size is usually expressed as an average of some type. Most easily obtained and of wide use is the simple arithmetic average, the summation of ND divided by the summation of N, where N is the number of drops in each size group and D is the diameter of that group. This method tends to weigh the average in favor of the numerous small drops; hence, more elaborate averages or means are frequently used such as the mass median, a median based on the drop mass rather than on the diameter. A jet nozzle (having no whirl or fan-producing elements) aimed with the aircraft slip stream produces the largest possible average spray drop spectrum for a given spray formulation and liquid pressure. Thicker sprays such as invert emulsions may be used to produce a still larger spray drop average. At present, there is no practical way to eliminate the small drops - they are only reduced in number as the shift moves towards the larger end of the spectrum. Two important factors must be considered before recommending that drift be reduced by producing larger drops. One of these is coverage. As drop size increases, the unit volume being held constant, the numbers of drops increase inversely to the cube of the ratio of their diameter. Thus, doubling the size, cuts the number of drops by 8. The result is greatly reduced coverage in constant lowered control, when control is frequently minimal at best. If the decreased coverage is compensated by increasing the total volume of liquid applied, the volume must be multiplied by 8, and this solution becomes impractical for aircraft. The second factor is phytotoxicity; certain chemicals cause speckling of fruit or burning of foliage as drop size is reduced.

For most drift studies it has been necessary to maintain at least minimum economic control of insects on the treated crop, while attempting to reduce the drift of chemicals to nearby crops. Types of chemicals, their formulation, type of application, and restrictions due to micro-weather conditions are the basic factors at one's disposal when working to reduce drift.

III Comparison of Atmospheric and Pesticide Aerosols

A Atmospheric Aerosols

(1) Orders of Magnitude

C.E. Junge has stated that the atmospheric aerosols form a spectrum which extends over almost four orders of magnitude. For convenience, the size range is usually subdivided into three groups. The smallest particles up to 0.1 micron radius are called

Aitken particles. The larger particles are classified from the 0.1 to 1.0 micron radius, and the giant are greater than 1.0 micron radius. The giant particles escaped attention for a long time because of their very low concentration and only recently were studied more carefully in connection with their potential role in rain formation. Virtually all of the pesticide aerosols contain a mass which put them in the giant particle size of greater than 1.0 micron radius. See figures below:

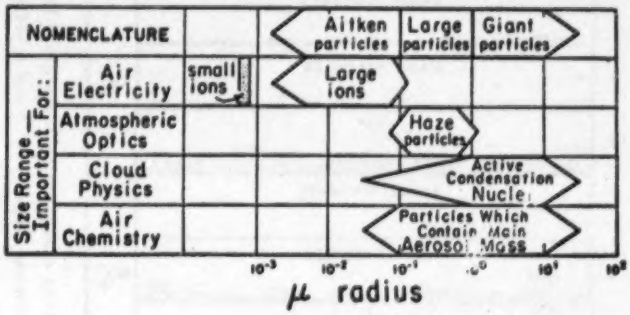

Fig. 21. Nomenclature of natural aerosols and the importance of particle sizes for various fields of meteorology.

For continental atmospheric aerosols the mass of large particles and that of giant particles are about equal, and both together represent a major part of the total aerosol mass. The Aitkin particles, despite their large numbers, do not account for more than 10 to 20% of the aerosol substance. An interesting summarized study showing the concentration of Aitken particles in different localities is shown below:

TABLE 27

CONCENTRATION OF AITKEN PARTICLES PER CM³ IN DIFFERENT LOCALITIES [a]

Locality	Number of:		Average	Average	
	Places	Observat.		Max	Min
City	28	2500	147,000	379,000	49,100
Town	15	4700	34,300	114,000	5900
Country (inland)	25	3500	9500	66,500	1050
Country (sea shore)	21	7700	9500	33,400	1560
Mountain					
500-1000 meters	13	870	6000	36,000	1390
1000-2000 meters	16	1000	2130	9830	450
> 2000 meters	25	190	950	5300	160
Islands	7	480	9200	43,600	460
Ocean	21	600	940	4680	840

[a] Landsberg (1938).

Professor Junge also did a study of the composition of large and giant particles in Florida in 1956 as is shown in the following figure:

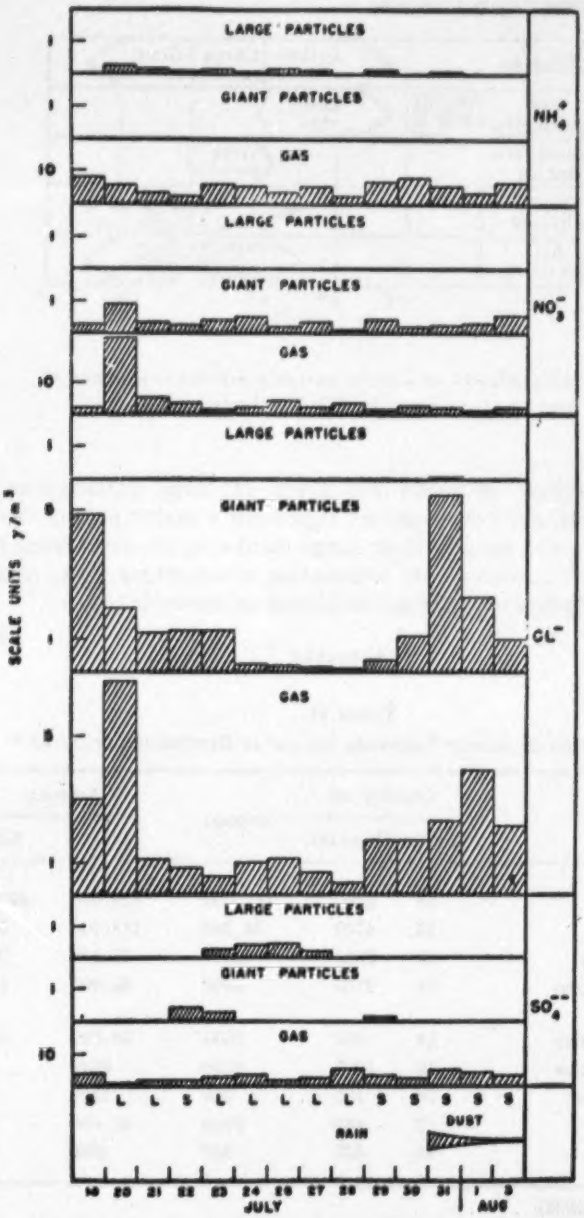

Fig. 40. The chemical composition of large and giant particles in Florida (Junge, 1956) and the concentration of the gases NH_3, NO_2, Cl_2, (?) and SO_2, measured simultaneously and plotted as NH_4^+, NO_3^-, Cl, and SO_4^{--} for better comparison. *S* and *L* indicate sea and land breeze, respectively. Note the different scales for gases and aerosols. (By courtesy of *Tellus*.)

(2) Concentrations and Analyses

The concentrations of acetone-soluble material in atmospheric aerosols, that is, an organic material, are remarkably high. Apparently, most of it is produced in cities and it is assumed that there is a natural background of about three to six micrograms per cubic meter. Reference is made to the estimates of Went, that 108 tons per year of terpene-like hydrocarbons or slightly oxygenated hydrocarbons are released by the biosphere into the atmosphere.

CHEMICAL COMPOSITION OF TROPOSPHERIC AEROSOLS

TABLE 34

PARTICULATE ANALYSES IN $\mu g/m^3$ FROM NONURBAN AREAS[a]

	Boonsboro	Salt Lake City	Atlanta	Cincinnati	Portland (Oregon)
Total load	68	55	71	45	86
Acetone soluble	8.7	6.2	9.3	9.0	12.6
Fe	3.7	4.1	2.7	2.4	3.6
Pb	0.1	0.1	0.9	0.4	0.3
F^-	—	—	Nil	0.26	—
Mn	0.00	0.04	0.11	0.07	0.04
Cu	Nil	0.28	0.01	0.19	<0.01
V	0.003	Nil	0.004	<0.001	0.002
Ti	0.26	Nil	0.13	0.01	Nil
Sn	<0.01	<0.01	<0.01	0.01	<0.01
As	0.01	0.03	0.01	<0.01	0.04
Be	0.0001	<0.0001	0.0002	0.0001	0.0001
$SO_4^=$	0.3	<0.01	0.5	1.9	0.4
NO_3^-	—	—	—	0.7	—

Chambers *et al* (1955).

In spite of the continuing interest in the meteorological role of aerosols, the knowledge of their chemistry is relatively meager, because too few chemists have given consideration to the problem. Although no single technique is adaptable to the entire range of aerosol particle sizes and compositions, methods exist for most cases in the size range above one micron, and a few substances can be identified at much smaller sizes. The electron microscope and other more sophisticated chemical analysis procedures are making it possible to overcome this problem.

(3) Dust Characteristics

Dust is made up of tiny particles of solid matter. Each particle contains many molecules and is small enough to be lifted off the ground by a gentle wind, so that it may float in the air. The size of dust is measured by microns which are subdivisions of a meter, which is about 39 inches long, and a micron is 1 millionth of a meter. A single inch contains about 25,400 microns. Dust particles range in size from 1/200th of a micron which is too small to be seen through a microscope, to 1,000 microns, easily seen by the naked eye. Dust particles are divided into three groups, according to their size.

Those that are large enough to be seen with the naked eye are over 50 microns wide. Just below them in size are the particles that can be seen only through the help of a microscope. They range in size from 1/5 of a micron to 50 microns. The smallest particle, too small to be seen in a microscope, are known as colloidal particles. Their width is more than 1/200 of a micron, but less than 1/5 of a micron. They can be seen in an ultramicroscope, where they reflect flashes of light the way large dust particles do in a beam of sunlight or lamplight. Even though most dust particles are heavier than air, and are naturally pulled down by their own weight, they are able to float in air. Several facts of physics account for this: for example, a wind exerts a force; also, moving bodies make their own wind; the bigger the surface against which a wind blows, the stronger is the force with which the wind pushes it; and lastly, when a solid object is broken, new surfaces are formed along the breaks. Because of this fact, when a small piece of matter is ground into dust, although its weight remains the same, its surface is increased tremendously. These physical facts account for why the dust aerosol particles can float in the air and air currents and wind do the rest and move them through the atmosphere.

B Pesticide Aerosols

(1) Physical Factors

All of the physical forms (dusts, granulars, or sprays) have a range of particle size in their makeup depending, in the case of dry materials, on the initial screening performed during manufacturing. Pest materials, for example, are screened to a range of 1 to 25 micrometers with a stated average of 80% to 90% of the formulation under 25 microns.

Many factors influence the movement of particles discharged from an aircraft, but some idea of the drift problem of various particle sizes can be obtained from Table I. As the table indicates, the drift potential from dusts is very high and is contrasted with the sprays. While 10 feet may be higher than an aircraft would be flying, it is evident that materials are lifted to this height by the wake in normal operations. No matter what form the material takes, the pattern of release is from the aircraft into the air wake created by the wing flight.

DRIFT OF AGRICULTURAL CHEMICALS

There are many factors that influence the movement of particles discharged from an aircraft, but some idea of the drift pattern of various particle sizes can be obtained from Table I (18).

TABLE I

Drop diameter microns	Particle type	Distance particle would be carried by a 3 mph wind, while falling 10 feet
400	Coarse aircraft spray	8.5 feet
150	Medium aircraft spray	22.0 feet
100	Fine aircraft spray	48.0 feet
50	Air carrier sprayers	178.0 feet
20	Fine spray and dusts	0.21 mile
10	Usual dusts and aerosols	0.84 mile
2	Aerosols	21.0 miles

(2) Vortex Patterns

This wake, (somewhat like the one following a boat in the water), carries the material outward toward the wingtips, then drops it in a swath of about wing span width. These vortex patterns develop into two distinct whirls at each wingtip with a strong central propeller wash. The latter has the undesirable characteristic of skewing the wake to one side of the aircraft's center line. Figures 1 and 2 show the development of this pattern in the wake of a fixed-wind plane and a helicopter. These figures were made by taking moving pictures of gravitationally-balanced (hydrogen-filled) balloons which were released from small cages fastened to the normal spray boom. The cages were opened simultaneously at a given point as the aircraft flew over a prescribed course. Overlay traces of the film gives the patterns shown. The distance between dots on the balloon paths can be compared with the scale at the top, which is equivalent to 10 miles per hour velocity.

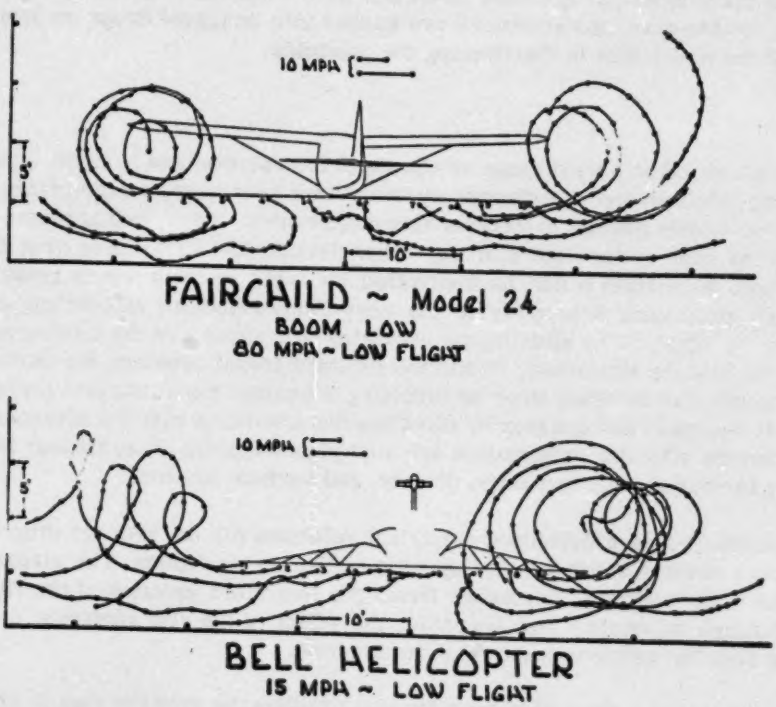

Plate I. Figs. 1, 2. Vortex patterns in the wake of passing aircraft.

(3) Dusting

In spite of the obvious drift potential of dusts, their use continues primarily on special coverage problems such as dense foliage, or vines and orchards where a significant crop depth occurs. Dust coverage is sometimes desired and is difficult to obtain with sprays. Dusts are generally more expensive both in initial cost and application costs on the basis of pounds of active material per acre. On the other hand, the formulation is fixed and no mixing is required at the sight of application; also the total pounds applied per acre is usually less with dusts than with spray formulations.

Dusting not only has greater drift hazard, but also results in less active chemical deposit. Some attempts have been made to increase dust deposit by electrostatic charging and by other techniques such as wetting the dusts as they discharge from the machine. However, to date, the success of these techniques for commercial application appears doubtful. Thus, dust applications are decreasing, especially by aircraft. In the early 1940's, over 60% of all aircraft applications in the United States were in dust form, but by 1963 this figure had dropped to an estimated 20%.

Granular materials would appear to offer the lowest drift hazard of any formulation. However, the usual size range of 30 to 60 mesh, which is equivalent to 600 to 200 microns, does not adhere to plant surface. Nor does the number of particles per pound of material provide sufficient coverage, or spreading, on the ground to insure contact with most insect species.

Granulars of the organo-phospherous materials have controlled certain insects, notably mosquitoes. In this case, the granulars are spread into irrigated crops or pastures and the action of the water aids in distributing the pesticide.

(4) Spraying

Spray applications offer a wind range of chemical formulation and particle size. Different atomizing devices and distribution systems have been used, ranging from the most common boom-nozzle system to various spinning brushes, discs, and screens. There is no evidence to date to indicate that any other devices had advantages over the boom-nozzle method. Atomization can be controlled by using various nozzle types from the hollow cones producing fine spray to the very coarse flooding and jet types. Further changes can be obtained by altering the operating pressures and the discharge angle in relation to the plane's airstream. Within the limits of initial breakup, the atomization of the given nozzle can be made finer by directing it against the airstream (usually at not more than 45 degrees) and coarser by directing the discharge with the airstream. Other important factors affecting atomization are such physical properties, already mentioned, of the spray formulation as viscosity, density, and surface tension.

Several researchers have developed empirical relations for the average drop size to be expected from various nozzles under specific operating conditions. The aircraft atomization system is complex, involving first, the hydraulic ejection of the liquid under pressure through an orphus and secondly, the effect of the slip stream's air velocity, which has a specific relation to the final atomization.

Frazer has developed a drop-size equation that predicts the average size to be expected from stationary nozzles. However, under aircraft conditions, the airstream provides further atomizing effects which Yeo has incorporated into a specific equation for flap fan-dash type nozzles. From Yeo's equation it can be seen that increasing the volume flow, surface tension and ratio of liquid velocity to the resultant of liquid and air velocity, will increase the drop size, while increasing the density, and the liquid velocity (alone) would decrease the drop size obtained.

(5) Drop Size Data

Drop size and frequency distribution information may be presented in many ways. One of the more expressive means are those based on number and mass of the drops and are termed number (NND) in volume (mass) medians (DND). In short terms, these medians are defined as the value that divides the number or volume of the spray into

TABLE II

Stearman aircraft	NMD	Arith. mean	VMD
Magnesium oxide (under plane)	94	140	340
Silicone (downwind)	67	84	158
For comparison a helicopter run shows (8002 fan nozzles, 40 psi, water base spray):			
Silicone (under plane)	103	144	263

two equal parts, 1/2 above and 1/2 below the median or 50% cumulative point. These medians are found by plotting on log versus probability paper either diameters for the number median, or volume (drop diameter cubed) against the percent of each size range found. Table II shows the drop sizes obtained from a run made October 8, 1962 with a Stearman aircraft equipped with fine atomizing nozzles of the hollow-cone type. The spray was a normal oil in water formulation. The data are from two sets of slides: one, magnesium oxide coated, placed under the direct swath of the aircraft; and the other, silicone coated, placed at stations downwind from the aircraft flight line.

Whereas the NND and the arithmetic air size closely correlates between the two runs, the DND is considerably higher in the case of the Stearman. This illustrates the need for examining the total spectrum of the spray tests rather than only the means. To fully evaluate the drop spectrum and the spray discharge of an aircraft, it is necessary to sample the airborn drops downwind from the flight line as well as from the ground fallout sample. The instrument now used for this is the cascade impactor which draws a continuous air sample through four rectangular orphuses. Airborn particles are impinged on slides placed behind the orphus. Several types of impactors have been made, but the Casella type appears best suited to this use. In these impactors, the air flow can be induced by a compressed gas aspirator (carbondioxide or other), and when adjusted to a given air flow the particles will impinge on the four slides in a decreasing size order. The first slide will impinge particles in the range of 50 to 6 microns, the second 6 to 2 microns, the third 3 to 1 micron, and the fourth from 1.5 to 0.7 micron. In addition, filter paper fifth stage can be used to catch even smaller particles.

IV Application Techniques in Relation to Pesticide Drift

A Formulation of Pesticides

In 1947, Brooks set a pattern of drift studies that is followed today. He stated the principle: "Underlying all problems of field application of toxic materials is the rate of settling of particles suspended in the air." Very small particles, up to 100 microns, fall according to Stokes' law. Brooks adapted other research for larger particles which was adopted by Akesson et al. In 1960 Rollins reported that a wind of 3 miles per hour would drift a 100 micron particle about 50 feet, while a 1 micron particle would drift 84 miles.

As has been indicated already, dust particles are very small and offer a great potential for drift. The attempts of Herrell et al., as reported in 1964, to control dust drift by using an electrostatic duster, as with other large field operations, have shown only limited success for electrostatic chargers. Another technique for reducing dust drift by wetting the dust as

it is ejected, has also had only limited success. The disadvantages of large particles and granulars have already been shown in spite of low drift potential.

The comprehensive South Texas Drift Experiments (at Texas A & M in 1962), show more pesticide was deposited on vertical plants with windy, stable conditions, and more on horizontal plates with light winds and turbulence. Also, more vertical deposition occurred close to the target suggesting that wind or horizontal transport is more important in border areas, and turbulent transport more important in distant areas.

Contrary to the expected condition, droplet size was observed to be quite variable. In one test larger droplets were found on the plates 327 feet distant from the sprayer than on the plates close to the sprayer. As the number of droplets was small, this may have resulted from chance, but it may have resulted from still another variable-evaporation of droplets. Under turbulent conditions, droplets below a certain diameter may evaporate before they fall. Pure water droplets of variable diameter, falling through air in a laboratory with a temperature of 86°F and 50% relative humidity had the following life time in seconds: 200 microns, 56 seconds; 100 microns, 14 seconds; and 50 microns, 3.5 seconds. In 1962 Amsden demonstrated that additives greatly reduced the rate of evaporation.

B Types of Distribution Equipment

Applications by aircraft usually produce greater drift than applications from ground equipment. The fact that the chemical is mixed with a greater volume of air counts for this difference, along with the effective speed. It is also obviously more difficult for a pilot flying a few feet above a field to start and stop the applications as accurately and to place the aircraft in the proper position to place the pesticide in the precise spot needed. Large ground sprayers using high velocity blowers probably produce a drift hazard virtually equal to that of aircraft. Studies have shown that normally there is more control over a ground rig than the velocity with which the chemical is discharged.

Two of the many advantages of aircraft over ground equipment are weather associated. No matter how thick the foliage because of excessive rain, or how muddy the soil, aircraft can deliver the pesticides.

Release patterns from a fixed-wing plane and from a helicopter are similar. Chemicals are released downward, dispersed outward, drawn upward near the wing tip or the rotor tip, rotated in this zone, and then settle to the ground. The vortex system - the rotation at the wing tip or rotor tip is a basic function of both types of equipment. The helicopter pattern is generally better than the aircraft because skewing is not a factor. Downwash from the helicopter has been shown to give better penetration of crop cover when hovering, but with forward speeds of 15 to 25 mth, this becomes insignificant. A practical swath width is usually limited to the positions of the vortices, thus normal coverage is limited to the wing span or the width of the rotor. The venturi or ram-air system ordinarily gives a swath width of 30 to 45 feet. Preliminary tests at Mississippi State University (Roberts et al., 1963) showed that a positive energy system, produced at the University, can produce a fairly uniform distribution over 80 to 100 feet. Such a system assures a wider dispersion of materials but undoubtedly increases the drift potential. Tests are being conducted with dispersal booms well below the aircraft to keep the materials away from the induced turbulence, thus aircraft drift drops to the same magnitude as that of ground equipment.

Variations in nozzles, which seems to be inherent in large-scale applicators, speed of material ejection, and speed of the applicator, as well as particle size and weather, seem to cause uneven distribution.

C Meteorological Considerations

(1) Atmospheric Motions

Drift problems of pesticide chemicals come about as a result of atmospheric motions which affect the diffusion and transport of these pollutants in the air. In using dust and sprays, care should be used to cover only the area where the pesticide is needed to destroy the unwanted pests. The fact that oil-based sprays have proven much more controllable than dusts accounts for the fact that in recent years sprays are used a great deal more than dusts to control pests. However, in spite of all the precautions that are used by many applicators, there are meteorological effects that play an important role in spreading, transporting or diffusing these sprays or dusts beyond the area that is intended to be covered. Some of the best drift research has been done in the three states which use about one-third the agricultural pesticides namely, California, Texas and Mississippi. Akesson et al. of California (in 1964) indicated three factors that must be considered in a drift study: (1) the type of distribution equipment and methods of use; (2) the formulation of the chemical used; and (3) the micrometeorological conditions prevailing during the interval of discharge from the applicators until its deposition on the target area.

(2) Meteorological Parameters

Meteorological conditions and parameters play a very vital role in the extent to which pesticide sprays or dusts drift or are carried by air currents or winds present at the time of application. The more important weather parameters include precipitation, air movement including wind direction, velocity, moisture, radiation, temperatures at the ground and at higher levels and the humidity at those levels. Occasionally, a single weather parameter may appear to be the controlling factor, but more often a complex of several elements is it. Some of the more practical considerations to be reckoned with are how weather affects the transformation as well as the transportation of pesticides, and how it affects the pest, and thus a need for a pesticide.

(3) Radiation Effects

The temperature lapse or difference in temperature between two heights above the ground is indicative of how stable or unstable the air may be at any given time. Advice on the general weather conditions for the day or period indicated can be obtained from the U.S. Weather Bureau or private meteorologists consulting their general weather surface and upper air charts for large and small areas to determine air movements, the passage of fronts, weather systems, and so forth. However, micrometeorological stations covering smaller areas for more accurate checks on the weather parameters described are necessary to more precisely determine the meteorological factors which will directly affect the ground or aerial applications as the case may be.

The normal daytime heating in the ground causes the air near the ground to be warmer than the air aloft. The measure of this difference in air temperature is called the temperature lapse rate. If temperatures at 8 and 32 feet are taken, and the 8 foot temperature found to be 0.1°F warmer, this particular difference is called the "Normal Lapse Rate." If the 8 foot temperature comes more than a 0.1°F warmer, it is called a lapse condition, and if the 8 foot level is cooler than the 32 foot, it becomes an inversion condition. With hot air at the lower levels, turbulent mixing will take place, carrying the lower air into the upper regions. However, if the lower levels are cooler, the warm air aloft remains on top and no vertical mixing can take place. Applying pesticide

chemicals under inversion conditions can greatly increase the drift hazard, since no vertical diffusion or movement of the chemical sprayed in air can take place.

(4) Climatology

In 1956 Schultz and others demonstrated the value of climatology in an application program. The hourly frequency of wind speed and direction are presented in graphical form for a number of rice growing areas. Schultz and others in 1961 went a step beyond this in demonstrating the effect of the delayed sea breeze in the target area. Many areas that receive pesticide applications are subject to mesocale wind patterns, and applicators should be made aware of these wind patterns.

Since winds normally increase with height, and most drift studies have measured winds at non-standard heights, (in some cases the height is not even recorded), it is impossible to compare drift measurements in one area with another. Temperatures and temperature gradient measurements share this same lack of standardization. Obviously, a great deal more standardization is indicated for future studies in connection with these parameters.

Two of the most comprehensive collections of papers dealing with the application of pesticides are, (1) The Proceedings of the Annual Texas Agricultural Aviation Conference and Short Course on Pest Control held in February 1962; and (2) the Report of the Fourth Agricultural Research Aviation Conference held at the University of California in July 1962. In addition to many individual contributions, the annual series of the Texas A & M Conferences which began in 1952 gives a history of the subject by graphically depicting the advance of the state of the art through the years.

Several excellent additions to the climatology of the United States which have a bearing on the drift have appeared in recent years. In 1961, Hosler tabulated the frequencies of inversions below 500 feet for all Weather Bureau radiosonde stations. One set of seasonal maps shows the percent of total hours when low level inversions occurred. Another set shows the maximum inversion frequency value reported at any of the four daily observation times. Monthly maps showing the prevailing direction and mean speed of the wind were published by the U.S. Weather Bureau in 1963. This data can be of real value to dusters and sprayers in their planting and operations.

(5) The Factors of Diffusion and Turbulence

Pesticide chemicals applied by an aircraft or ground equipment and intended for crops have to travel through a layer of air. The diffusion characteristics of this layer can thus strongly affect the ground concentration pattern of material with a low density or slow gravatational settling.

There is molecular diffusion in the atmosphere among its molecules just as diffusion in the spreading of heat throughout the median of a solid metal. However, in the atmosphere, the rate of molecular diffusion is about 1/10,000 of the turbulent diffusion rate and is therefore neglected. In analogy with molecular diffusion, turbulent diffusion can be visualized as taking place because of the random motion of fluid over a distance and with frequency, which are characteristic of the particular location within the fluid.

The molecular diffusion rate for a solid at a fixed temperature is constant, but the analogous turbulent diffusion rate varies considerably. For example, high wind speeds are characterized by high diffusion rates, neglecting the transport of the diffusing substance downwind, due to a high frequency of the random motion. The turbulent diffusion rate also increases with increases of the characteristic distance over which the random motion takes place. This distance is directly proportional to the height above the ground and to the size of the roughness elements on the ground below and upwind,

and is strongly modified by the temperature structure of the atmosphere. Under unstable temperature conditions, i.e. decreasing temperature with increasing height, these effects tend to increase this characteristic distance; and under stable conditions, increasing temperature with increasing height, this characteristic distance is decreased because of the tendency of the colder air near the ground to remain in one place.

Temperature conditions near the ground change diurnally. As the sun rises, incoming solar energy warms the ground and hence the adjacent air. During the morning hours, the temperature conditions are slightly unstable, but the greatest instability occurs at the time of maximum temperature in the afternoon. As the sun sets and the solar energy ceases, the hot ground cools rapidly by radiational loss to the sky, and hence cools the immediately adjacent air. This results in very stable conditions, which persist throughout the night.

An irrigated crop will also modify these temperature conditions because some of the incoming solar energy is utilized in evapo-transpiration from the crops so that less is available for heating the air. Thus the air over an irrigated crop will never be as unstable as that over dry land. In fact, it is even possible to get stable conditions over an irrigated crop several hours before sunset. This is even more significant if the irrigated field has a large dry area immediately upwind so that hot air is being carried across the colder field.

Thus, the diffusion rate of a cloud of gas or small particles in the atmosphere is affected by the height of the cloud, the wind speed, the roughness characteristics of the ground, the time of day, the amount of clouds present (for their inhibiting affect on the radiational exchange), the type of ground cover (irrigated or non-irrigated), and the size and orientation of the irrigated area with respect to dry areas.

In the Technical Note #32 of the World Meteorlogical Organization there is a thorough discussion of many of the problems in agricultural aviation. It points out that turbulence is the factor of real importance in applying chemicals. The Technical Note refers to the following equation by Yea and Thompson as a practical estimate of low level turbulence:

$$\text{Turbulence} = \frac{\text{Temp (10m)} - \text{Temp (2.5m)} + (7.5) \times \text{Dry Adiabatic Lapse Rate}}{(\text{Mean Wind Speed 5m})^2}$$

Very few areas are equipped to measure the required weather elements. Many stations in this country do measure soil temperature and standard air temperature; and the following formula, based on the above theory, will give an operational forecast of turbulence:

$$\text{Turbulence} \sim \frac{\text{Soil Temp (2 in.)} - \text{Air Temp (5 ft.)}}{(\text{Average Wind at 18 in.})^2}$$

Soil Temp (2 in.) - Air Temp (5 ft.) Degree Fahrenheit	Wind (18 in.) Miles Per Hour	Turbulence Lowest 10 ft.
< -5	0 m.p.h.	None Very Stable
0 to-5	0 m.p.h.	None
near zero	> 3 m.p.h.	None
near zero	0 to 3 m.p.h.	Very Light
1 to 4	> 3	Light
1 to 4	0 to 3 m.p.h.	Moderate
> 4	> 3	Moderate
> 4	0 to 3 m.p.h.	Heavy

(6) Diffusion Research

Diffusion in relation to atmospheric fallout and air pollution, is a large scale phenomenon in comparison with drift. Diffusion near the earth's surface, in relation to the surface energy balance and evapo-transpiration, is a comparatively small scale phenomenon. Both have received extensive study and the results can be applied in drift research. The U.S. Weather Bureau is cooperating with many other organizations in studying those scales of diffusion. The aim of large scale diffusion research is to develop methods for predicting a concentration of noxious effluents, which are the airborn waste products of our increasingly complex society.

Analyses of wind and stability and the climatology of these elements are the basis of prediction. Turbulent conditions cause the effluents to swirl downward and reach the ground near the source, thus turbulence must be avoided. Inversion conditions, which permit long period of horizontal diffusion, allow the elluents to spread and thus dilute over a wide area, and are therefore conducive to drift. Akesson testified in 1964, "The worst weather conditions found so far are where an area temperature inversion exists combined with a low wind (under 5 miles per hour). Here the drift residue downwind can be as much as 10 times higher than that occurring during good weather conditions."

Smoke puffs have been used as visual indicators of particle transport prior to the release of radioactive wastes from a stack since the early 1940's. The Proceedings for the Texas Agricultural Aviation Conference showed how smoke puffers have been adapted to drift work. They are useful in research and in actual operations, they can serve as an inexpensive check on the actual drift of an application. So far, they have not been used very often.

Although smoke puffers have been useful in controlling stack releases, they have been supplemented by elaborate prediction models. The development of analogous micrometeorological prediction models in and near a plant canopy has suffered from one basic limitation. So far, it has not been possible to define the aerodynamic roughness effect of the boundary in terms of the height, density, and drag characteristics of the plant canopy.

Most turbulence research workers define turbulent transport in terms of mean velocity and its derivatives. The logarithmic velocity profile represents the variation of the mean wind speed with height in the surface boundary layer. For rough flow the profile may be approximated as follows:

$$\frac{\overline{U}}{U_*} = \frac{1}{K} \ln \frac{(Z)}{(\overline{Z}_o)} \qquad Z \geq Z_o$$

Where the subasterisk is the friction velocity, K is Von Karman's constant, and Z_o is a constant called the roughness length, which is equal to the average height of surface irregularities divided by 30. The 0-plane displacement is an empirically determined constant introduced into the logarithmic velocity profile for the purpose of making the profile applicable to very rough surfaces. It is regarded as the datum height above which normal turbulent exchange takes place. It is comparable to the depth of the air layer trapped among the vegetation.

Kutzback in 1961 evaluated those variables in his new classic "Bushel Basket" experiments. Bushel baskets were placed at various distances from each other on a frozen lake surface. He showed that the roughness length and the zero-place displacement increased with increasing basket density.

(7) The Tracer Technique

The selection of the tracer material for evaluation of spray drift is based on the following desirable characteristics; (a) high sensitivity, measurements down to 0.01 micrograms; (b) rapid quantitative analysis procedures available; (c) soluble and spray mixtures with minimum physical effect on atomization and droplet evaporation; (d) distinctive property to differentiate from background or natural-occurring substances; (e) stable or predictable concentration relationships under environments encountered during experiments; (f) moderate costs; (g) nontoxic, and acceptable under the Food and Drug Administration regulations.

One of the most common tracer systems involved uses soluble dyes (water or oil-soluble), subsequently measured by a colorimeter. A more useful technique is that involving certain metalic salts (manganese sulfate and strontium chloride) which, when analyzed with a plain spectrophotometer, provides a rapid, accurate tracer technique. However, the soluble fluorescent dyes that are used by air pollution scientists have far greater sensitivity than any of the others.

To obtain the most satisfactory fluorescent dye, the series of materials are checked for (a) degradation and sunlight, (b) degradation from heat, and (c) chemical or physical loss in sensitivity when added to spray formulation. From this work, Brilliant Sulfoflavine was chosen as the most desirable dye. An Aminco-Bowman spectrofluorometer has been used to establish the most efficient spectral response (420 micrometers), which aided in the proper selection of filters for the Turner machine.

For drift tests at the University of California by Akesson and Yates, spray formulations were made up in bulk mixing tanks and included the actual pesticide toxicant, emulsifier, fluorescent or other tracer, and diluting water. The applications were put on by aircraft

flying 10 to 15 passes (roughly equal to a 40 acre treatment) on a fixed course, upwind from an alfalfa field 1/2 to 1 mile length. Analyses were run on alfalfa samples by residue laboratories for the pesticide residue, using sensitive chromotographic techniques. Mylar plastic sheets (9 x 18") were laid on the selected downwind stations corresponding to the points where the alfalfa samples were taken. Four or more replicates were taken at each station.

(8) Field Instrumentation

In addition to the mylar sheets which were used for collecting all samples for quantitative analysis, glass slides (3-1/4 x 4") were placed at each station for drop-size analysis. For airborn samples, Staplex samples with filter paper collection, and cascade impactors with glass slides were located at several of the downwind stations as shown in figure 5.

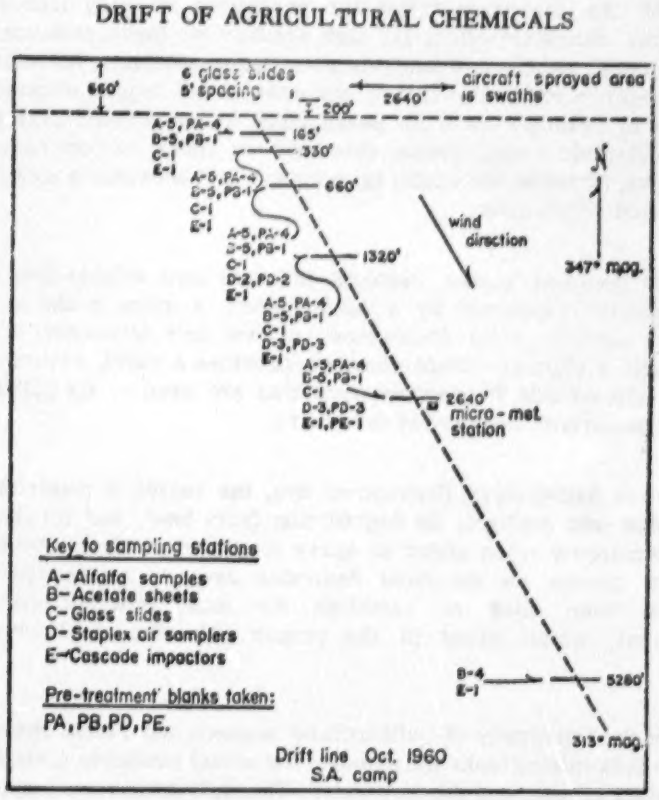

Fig. 5. Field layout showing distribution of sampling stations in relation to drift line (dashed line).

The engine-powered generators furnished electrical power to Staplex devices while the cascade impactors were operated by compressed carbon dioxide gas aspirators. The air sampling rates on these are adjusted to approximately the velocity of the wind passing the stations.

For most tests the basic formulation was an oil-water emulsion as noted, applied at a rate of about 10 gallons per acre. All aircraft used Stearman-biplane types using a boom nozzle system with hollow-cone nozzles. These gave a fine atomization spray with droplets of an arithmetic mean diameter between 100 and 150 microns. See tables I and II which follow for detailed information on sprayed drift residue and weather data in connection with these investigations.

(9) Test Data on Tracers

All drift data, pesticide residue, and tracer, are ploted on log-log-graph form as shown in Figure 3. This graph indicates tracer deposit in gammas micrograms (per sq. foot of deposit area) mylar sheets 6 x 18"), per pass of the aircraft.

Figure 3 shows the curves of the June 15 and 16, 1961, runs at camps over green alfalfa. The lower curve indicates a run with a Stearman airplane using coarse atomization (31-D8) nozzles aimed back. September, October and November runs of 1961 were made in the Yllo Bypass near Davis, California--the figures shown by studies of Yates and Akesson.

The reduced drift, as indicated by the October 16 run, is related to (1) coarse atomization and, (2) the possible effect of applying over a dry field where turbulence may act to carry materials out of the sampling area to greater distances downwind. The difference between the June 15 and 16 runs is primarily due to the higher wind velocity of the June 16 run.

Figure 4 shows drift difference between a normal type formulation, (usual 10% oil in water), and thickened invert emulsion; the latter is intended to produce a coarse droplet spectrum. The two top curves compare invert and normal emulsion as applied by a Stearman aircraft using the coarse atomizing D8 jet nozzles. However, the arithmetic average drop spectrum does not bear out this intention; the invert and normal runs gave about the same 300-micron average drop size. As a result, little differences in drift deposit can be shown. Apparently the high shear turbulence on the aircraft weight has more affect on atomizing the liquid than the viscosity has in reducing this atomization. However, comparing the two as applied with a ground rig, (on the lower two curves, November 8, 10 runs), indicates about 10 times less drift for the thick invert compared with the normal emulsion. Wind velocities for the invert run were 10 to 12 miles per hour as compared with 5 to 6 miles per hour for the normal emulsion run. Thus, both increased wind and finer spray acted to make the difference in the drift.

TABLE I

Spray Drift Residue and Weather Data Taken During Runs as Noted at S. A. Camp Company, Shafter

Drift from 20 Swaths or 40 Acres on a 1/2 Mile Run

Date	MICRO-WEATHER DATA				SPRAY DATA		ACTUAL CHEMICAL RESIDUE PPM ON GREEN ALFALFA 12-18" HIGH						
							Feet downwind						
	Velocity mph at 8'	Temp. 8 ft. F°	Temp. diff. 32'-8'	RH %	Spray atomization	Pounds active per acre	100	200	400	600	1000	2000	4000
23 June 1960	3.5-6.4 ave. 4.7	101 to 103	0 to normal lapse	22	Fine (under 150 microns)	0.5	0.5	0.3	0.14	0.08	0.04	--	--
					Med. (150-300 microns)	0.5	0.28	0.16	0.07	0.04	0.02	--	--
3 Oct. 1960	3-4 ave. 3.5	83 to 85	+4°F Strong inversion	50	Fine	0.5	0.95	0.84	0.69	0.55	0.38	0.18	0.06
15 June 1961	ave. 5	101 to 105	+4°F (Localized inversion)	40	Fine	0.5	0.68	0.3	0.15	0.09	0.05	0.016	0.007
23 June 1960	Run at same time as 23 June above				Fine	1.5	0.9	0.55	0.3	0.19	0.11	--	--
					Med.	1.5	0.5	0.3	0.14	0.08	0.05	--	--
15 June 1961	Run at same time as 15 June above				Fine	1.5	2.0	0.9	0.45	0.27	0.15	0.05	0.02
24 June 1960	6-7 ave. 5	90 to 91	0 to normal lapse	25	Fine	4.5	7.0	4.5	2.5	1.6	0.8	0.31	--
					Med.	4.5	4.0	2.5	1.3	0.75	0.35	0.1	--

Material, 7-8 total gal/acre, applied by Stearman, 450 hp aircraft, 3-5' above crop flying on a 1/2 mile run for 20 passes or 40 acres. Fine sprays: 36, D-8 (June 61, D-10) tips with No. 46 whirl plates (one case 3 October without plates) aimed straight down. Medium spray with 38, D-8 tips only, aimed down 45 degrees and back. Pressures 20-30 psi at boom.

TABLE II

Approximate Drift Residue in PPM to Be Expected on 12 to 18 inch Alfalfa at Downwind Distances as Noted

Emulsion Formulation Applied at Total of 10 Gallons with One Pound Active Chemical Per Acre

MICRO-WEATHER DATA				SPRAY DATA		CHEMICAL RESIDUE PPM ON GREEN ALFALFA IMMEDIATELY AFTER SPRAYING					
Velocity mph at 8 feet	Temp. F° 8 ft.	Temp. diff. 32-8 feet F°	RH%	Spray atomization	Pounds active per acre	Feet downwind					
						100	200	400	600	1000	2000
BEST WEATHER CONDITIONS FOR APPLICATION											
3 to 5	70 to 95	zero to normal lapse	20 to 50	Fine (under 150 microns)							
Drift from 80 swaths, or 160 acres on a 1/2 mile run.....					1.0	1.76	0.84	0.46	0.32	0.198	0.094
Drift from 40 swaths, or 80 acres on a 1/2 mile run.....					1.0	1.63	0.74	0.38	0.26	0.144	0.046
Drift from 20 swaths, or 40 acres on a 1/2 mile run.....					1.0	1.36	0.6	0.3	0.18	0.1	0.032
CALM, STRONG INVERSION WEATHER											
2 to 3	70 to 100	+2 to +5	40 to 50	Fine	1.0	The ppm varies from 3 to 10 times the above residue values. It appears that the larger multiplier should be used for the greater downwind distances.					
STRONG WIND, TURBULENT WEATHER											
8 to 10	70 to 110	0 to -5	20 to 40	Fine	1.0	The ppm varies from 3 to 6 times the residue values in columns above.					

For two pounds active chemical, double ppm data in above tables. For 0.5 pound active, divide by two. Other amounts of active chemical would be taken proportionally for emulsion formulations.

For medium atomization sprays (150 to 300 microns) divide ppm residue by two in the tables above.

All data above is in ppm on green hay basis. Curing the hay (water loss) tends to increase residue, while degradation (chemical and physical loss during curing) tends to reduce this residue.

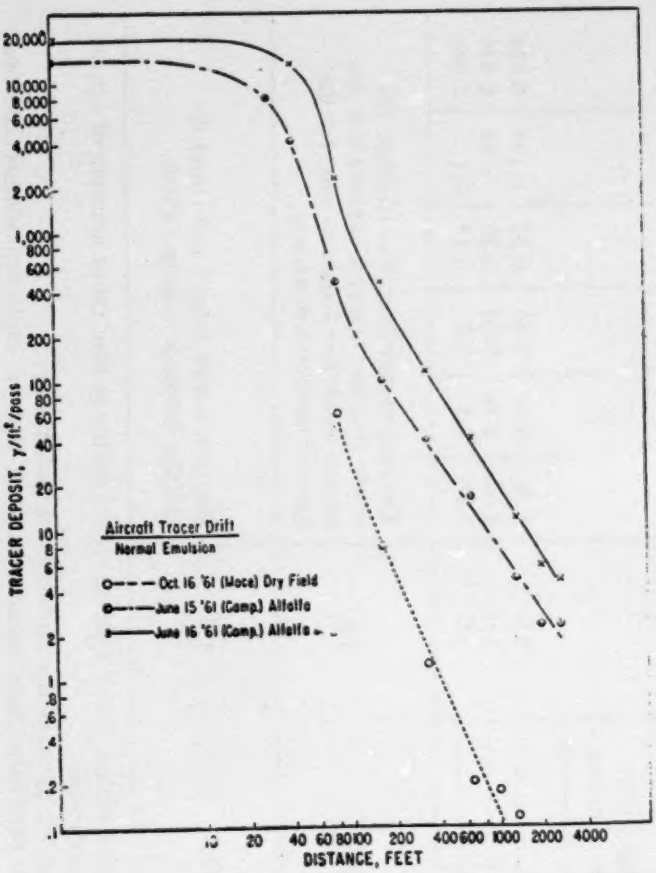

Figure 3.--Curves showing aircraft tracer drift under the conditions shown.

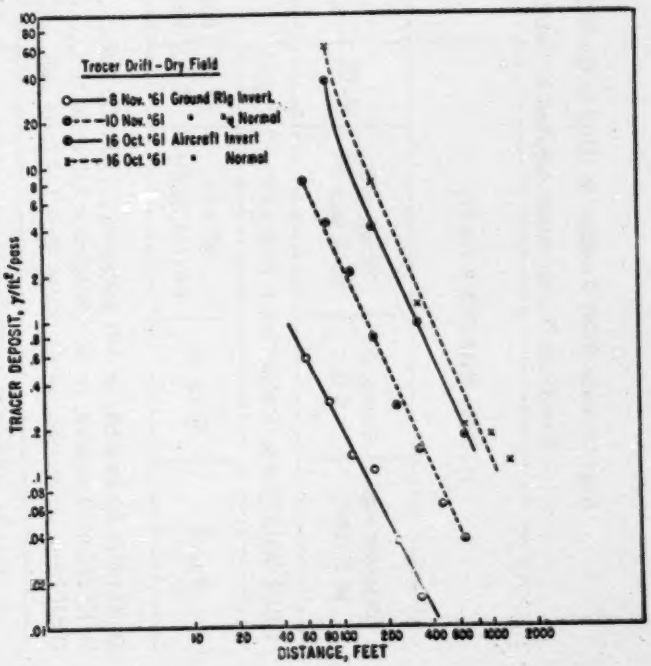
TRACER DEPOSIT, y/ft²/pass
DISTANCE, FEET
Tracer Drift - Dry Field
8 Nov. '61 Ground Rig Invert.
10 Nov. '61 • " Normal
16 Oct. '61 Aircraft Invert
16 Oct. '61 • Normal

Figure 4.--Curves showing aircraft tracer drift under the conditions shown.

Table 4, which follows, summarizes the pesticides drift data to date by indicating the safe distances that various chemicals commonly used in California alfalfa-growing areas may be applied and not cause a detectable residue to appear in milk or dairy animals being fed the hay. In preparing this table, drfit and micro-meteorological data were combined with specific pesticide chemical degradation (column 5, losses of chemical after application, both physical and chemical) and specific chemical feed-through information. The latter was obtained in the form of maximum pesticide levels on alfialfa hay in ppm fed to dairy cows, which would not result in a detectable residue in the milk. These varied from 0.1 to 1 ppm on alfalfa hay. As stated before, DDT has a tolerance in California of 0.5 ppm. All others fall under the instrument 0 concept or minimum detectable level. Hay-curing was considered to increase the residue by a factor of 4.

From this information and rate of active pesticides used, the data of table 4 were prepared. The last three columns on the right indicate the safe distances that various pesticides may be applied upwind from alfalfa fields under good weather conditions as listed. The table is intended to serve as a guide for the grower and applicator of agricultural chemicals and, if carefully used, should at least reduce the chances for drfit occurrence. The chemicals other than those listed, specific information on degradation and animal feed-through can be applied to the drift information to give safe distance downwind from the specific chemical application.

D Eradication of Pests

Unlike most pesticide programs which are intended to control or limit the maximum level of pest populations, eradication programs are intended to eliminate the pests. Because chemicals are spread over an entire target area on an eradication project, drift, in the usual sense of the word, is not usually as great a factor to be considered.

Several of the better known eradication programs in recent years include the Gypsy Moth Project in the Northeast and the imported Fire Ant Project in the South. Similarly, the Japanese beetle and Dutch elm disease control programs in the Midwest could also virtually be labeled eradication programs.

To eradicate the Gypsy Moth, DDT in an oil emulsion was applied from the air on nearly one million acres in the Northeast in 1956. An additional three million acres, two million of which were in New York State, were treated in the following year. When Huddleston Et al. analyzed residues from this program in 1960 the chemical was found to be highly persistent on forage and little affected by weather. Fortunately, the growth of new grass with its great increase in mass and volume was found to be a very important factor in residue loss.

The fact that wind has been found to be the primary factor in the progressive spread of Gypsy Moth larval, or catapillar stage, was amply demonstrated when the New England hurricane of 1938 spread the moth from New Jersey into Pennsylvania and New York. The knowledge, too, that temperature and, to a lesser extent, moisture influenced the development of the larval stage makes control practices more specific.

In 1963 Rhoades studied the effects of the application of heptachlor granules for the eradication of the imported fire ant. Samples were taken over a three year period starting one year before application. In the treated area, the imported fire ant was eradicated. Other insects in the area were severely reduced in numbers for several months following treatment, but returned to approximate normal populations within one year and maintained these populations during the succeeding year.

TABLE IV

Conditions under which certain pesticides may be applied in areas where alfalfa hay is being grown in California and which resultant residues on the hay, because of drift, will not result in detectable residue in milk when the hay is fed[1]

Chemical	Rate per acre	Weather conditions[2]		Half life of chemical in days	Safe distances downward from point of application to alfalfa hay. Distances based upon drift pattern of fine emulsion sprays, rate of application, half life chemical and interval between exposure of hay to drift and cutting date		
		Wind velocity in m.p.h.	Temp. at[3] 32 ft. minus Temp. at 8 ft. F°.		0-days[4]	6-days	12-days
DDT	1 1/2 lb.	4-7 m.p.h.	Zero to normal lapse rate	6	1,200 ft.	600 ft.	300 ft.
Toxaphene	3 lb.	same	same	5	1,600 ft.	700 ft.	250 ft.
	4 lb.	do	do	5	1,800 ft.	800 ft.	300 ft.
Endrin	1/2 lb.	do	do	7	1,800 ft.	1,000 ft.	500 ft.
Thiodan	1 lb.	do	do	5	500 ft.	250 ft.	100 ft.[5]
Kelthane	1 lb.	do	do	6	1,200 ft.	600 ft.	300 ft.
Tedion	1/2 lb.	do	do	8	500 ft.	350 ft.	100 ft.[5]
Aramite	1 lb.	do	do	5	2,900 ft.	1,200 ft.	600 ft.

[1] These distances are based upon a single exposure between cuttings. If several applications are made in the same vicinity at approximately the same time, the drift residue on a particular alfalfa field downwind will probably be cumulative and thus the amount of deposit may exceed that upon which these calculations are based.

[2] These figures apply only to what is termed "good" weather conditions in the terms of wind velocity and temperature lapse rate as given here. Any other set of conditions will result in a different drift pattern. Applications under strong inversion conditions or in windy turbulent weather, when the wind velocity is from 8 to 10 m.p.h., will increase residue deposits from 3 to 10 times, depending on the distance downwind. Larger increases in deposits will occur at the farther distance downwind. Applications under these conditions will increase the drift hazard by many times.

[3] See text for explanation of temperature lapse rate and inversion condition.

[4] A ratio of 4 to 1 for the increase of apparent residue during the cutting process is assumed for all materials. At the zero day period, no degradation of the chemical assumed.

[5] We consider the application of any of these materials at distances closer than 100 feet to alfalfa not a safe procedure regardless of weather conditions or interval between time of application and cutting of the hay.

[This guide is intended to serve only to help in determining the feasibility of using certain materials in areas where hay is being grown. If the conditions listed in this guide cannot be met, then it would not be safe to use these chemicals.]

Rhoades, University of Florida Entomologist, and Davis, Weather Bureau Agricultural Meteorologist, are conducting studies in Northwest Florida relating to fire ant development and activity, including their mating flights. With more accurate predictions of these flights, a short-lived chemical can be applied at the critical period and thus minimize the hazards to wildlife and other insect species.

Present knowledge of weather influence on fire ant activity improves control efficiency and reduces residue hazards. A Weather Bureau Advisory distributed by the press in the Southeast, is a good example of this:

WEDNESDAY *MARCH 18, 1964* *1000 AM EST.*
U.S. WEATHER BUREAU *QUINCY FLORIDA*
FARM WEATHER NOTES *NORTHWEST FLORIDA*

WEATHER CONDITIONS HAVE NOW BECOME RIGHT FOR A RAPID INCREASE IN FIRE ANT ACTIVITY. FIRE ANT ACTIVITY REMAINS QUITE DORMANT AS LONG AS SOIL TEMPERATURES ARE LOW. MEAN SOIL TEMPERATURES ARE NOW APPROACHING THE MID STATES AT THE TWO-AND FOUR-INCH LEVELS AND ARE IN THE LOWER SIXTIES AT THE RIGHT-AND TWELVE-INCH LEVEL. THESE SOIL TEMPERATURES ARE SUFFICIENTLY HIGH FOR THE HATCHING OF NEW FIRE ANT BROODS--IN FACT THE FIRST NEW BROOD TO BE REPORTED WAS DETECTED THIS WEEK.

WEATHERWISE--THIS WOULD BE AN EXCELLENT TIME TO APPLY CHEMICALS FOR CONTROL AND ERADICATION OF THE FIRE ANT. FARMERS WANTING TO APPLY TREATMENT SHOULD CONSULT THEIR COUNTY AGENT FOR RECOMMENDATIONS.

Because eradication programs for mosquitoes, gnats, the Japanese beetle and the Dutch elm disease often involve the food chain, this causes pesticides to affect unsuspected areas in increased proportions. A classic example at Clear Lake, California was when DDD (Orthene 3-D, Rhotane) was applied in a limited control program in 1949. After increased applications were made in 1954 and 1957, the Western grebe suffered from the latter two applications even though the grebe did not consume the DDD directly. The grebes ate smaller carnivores which had eaten herbivores, which in turn, had eaten plankten, which had absorbed the poison from the water in the lake; the poison had reached the lake either from drift or from rain wash. In 1964, George stated, "Animals at the end of the complex ecological food chain seem particularly vulnerable."

V Weather Modification of Need for Pesticides

A Agricultural Meteorology

Weather exerts an important influence over insects, disease, weeds, and exercises a natural control over many pests. The fact, also, that weather influences the vulnerability of pests to control practices is of even greater potential. By availing himself of services of Weather Bureau or private agricultural meteorologists, an applicator may be able to use pesticides when conditions are such that the pests will be particularly vulnerable.

B Weather Effects

(1) Insects

a Mites

In the State of California there are six major species of Mite pests which are of particular concern to the citrus growers. Extreme weather limits the distribution of Mites in various areas, and weather parameters in general determine the way the Mites are controlled.

For example, the citrus bud mite, which is confined to the coastal districts, is also further confined under the bud bracts of the citrus trees. When, under certain weather conditions, these mites migrate to new buds, they can be easily controlled by the use of residual type pesticides supplied on mist sprays. However, at other times, the spray must wet the buds in order to contact the mites to obtain adequate control, which requires a full coverage application.

Adult and nymphal stages of citrus red mite inhabiting interior areas, are reduced by hot, dry winds. Control applications, while the mite population is largely in the egg stage, during these adverse weather conditions, produce more effective control than is normally obtained.

In 1964 Jeppson found that lemon fruit which had been subjected to hot, dry weather was less favorable for white egg production than similar fruit obtained from cool morning coastal orchards.

Some weather extremes adversely affect not only the mite populations, but also the crops which they damage.

b Desert Locust

In 1963 Rainey traced the movements of locusts on the macro and mesowindfield scales in a comprehensive report which related the biology and behavior of desert locusts to weather. This is another good example of how knowledge of a pest and its relation to weather enables the control agency to improve its efficiency.

c The Wintering Habitats

Since many pests cannot withstand the rigors of winter except for the protective microweather conditions in which they inhabit, the destruction of the over-wintering habitats would reduce pest population.

(2) Crops

a Cotton

The important Southern crop of cotton is reduced in quality and quantity by cotton bowl rot. In 1964 Newton Et al. reported that the degree of bowl rot infection, which is most prevalent just before harvesting time, is intimately related to the microweather within the plant zone. Mississippi measurements indicated that increased light, wind and temperature, and decreased relative humidity reduced the amount of the bowl rot fungus. Defoliation with pesticides before harvest time allows more sunlight within the crop zone and permits greater ventilation, reducing the bowl rot infection.

b Alternate Row Planting

Increased quality in yield of crops has been accomplished by a placement of one, two, four, or more rows of a crop alternately between some number of unplanted rows. Skiprow crops increase the amount of light reaching the plant and increase the ventilation. This reduces some insect populations, some disease developments, and makes weed control less expensive. As this case illustrates, other cultivation practices may reduce the requirements for pesticides.

c Additional Control Methods

In 1960 DeWitt Et al. mentioned a number of other control methods in the Pesticide Wildlife Review, such as: particular times for planting and harvesting, proper

fertilization and control of water level, and crop rotation. These practices, which tend to impose natural controls on many pests, and the various weather thresholds which affect pest development should be evaluated in the terms of the specific pest. Then, by adopting cultural practices which will modify conditions to cause unfavorable pest microweather will make it possible to reduce the use of chemical pesticides. Biologists have asked why there isn't a biological classification of climate for all agricultural areas. In 1962, Landsberg, recognizing as do others that it would be almost physically impossible to classify all farming areas by any practical number of climatic variables, stressed that there can be no universally valid climatic classification that can be applied to all biological processes. He further indicated that biologists have rarely defined the exact climatic conditions that influence the particular process on which they are working. Until this is done, the vast amount of climatalogical information, which is currently available for most agricultural areas in the United States, can be of only limited use to the biologist.

VI Weather Advisories

A U.S. Weather Bureau Services

Many chemical applicators have either not used or not had available proper agricultural meteorology forecasts or advisories to do a proper job of dusting and spraying of pesticides. This has undoubtedly contributed to the lack of proper control, particularly from the standpoint of drift, as well as exacting the greatest effect at the proper meteorological times in applying pesticides.

In recent years the Weather Bureau has expanded its specialized agricultural weather services and produces operational weather advisories in a number of areas, and specialized dusting and spraying advisories are now a part of this service. As the Chief of the U.S. Weather Bureau stated in 1964: "Weather forecasts are extremely perishable. . .and its product must reach the consumer quickly. . .a teletypewriter circuit has been set up in each agricultural weather service area, Operating 24 hours a day throughout the year, the circuit brings timely weather information to radio and television stations and newspaper offices in the area. . . . The Dusting and Spraying Advisories emphasize weather conditions for low-level aircraft flights as well as those factors important to application of agricultural chemicals." A typical advisory distributed to growers and applicators throughout the news media of radio and television follows:

5:00 AM *MONDAY* *SEPTEMBER 9, 1964*

AGRICULTURAL AVIATION ADVISORY FOR MID-SOUTH

CLEAR SKIES AND LIGHT WINDS GAVE IDEAL RADIATION CONDITIONS LAST NIGHT. HEAVY DEW COVERS MOST AREAS. GROUND FOG FORMED OVER MUCH OF THE LOUISIANA DELTA, SOUTHEAST ARKANSAS AND NORTH AND CENTRAL MISSISSIPPI AND VISIBILITY IS REDUCED TO ONE TO THREE MILES, BUT WILL INCREASE TO SIX MILES OR BETTER BY 7:30 AM

SKIES WILL BE CLEAR TODAY EXCEPT FOR ONE TO THREE-TENTHS OF CUMULUS CLOUDS AT 3500 FEET. DEW WILL DRY BY 9 AM. WINDS WILL BE LESS THAN 5 MPH TILL 9 AM, WILL BE SOUTH 7 TO 10 MPH 9 AM - NOON, SOUTH 10 TO 15 MPH THIS AFTERNOON BUT LESS THAN 5 MPH BY 6 PM. NO RAIN TODAY OR TUESDAY BUT ABOUT A THIRD OF THE AREA WILL HAVE SHOWERS WEDNESDAY.

GOOD DUSTING AND SPRAYING CONDITIONS TODAY TILL 9 AM AND AFTER 6 PM. DEW WILL BE MODERATE TO HEAVY TONIGHT. TEMPERATURES WILL BE 70 DEGREES OR HIGHER AND CONDITIONS ARE FAVORABLE FOR APPLYING DEFOLIANTS. THE EXTENSION SERVICE ADVISES THAT BOLLWORMS ARE STILL PREVALENT IN MANY YOUNG, GREEN COTTON FIELDS AND SHOULD BE CONTROLLED. SOME OLDER, DRY FIELDS DO NOT NEED CONTROL. IF IN DOUBT, CALL YOUR COUNTY AGENT.

B Synoptic Weather Map Patterns

Certain typical weather map patterns are associated with favorable weather for applying dusts and sprays. In 1957 Bourke carried the weather map pattern system further by going directly from a synoptic weather map to a plant disease advisory. Because pest outbreaks of potatoe blight in Ireland were related to certain synoptic map features, when they appeared or were expected to occur, he issues a blight forecast. Wallin Et al. in 1960 extended this principle to the 700 mb Chart in the North Central United States, while Scarpa Et al. in 1964 expanded this synoptic approach up to the 500 mb Chart to make routine advisories for downy mildew of lima beans in New Jersey.

The consensus of opinion reported in the literature is that accurate, timely, easily understood agricultural advisories are necessary if pesticide applications are to be efficient as well as safe. Agricultural meteorology is related to the use of pesticides in: (1) transportation and (2) transformation of pesticides, and (3) pests and thus the need for a pesticide.

It is generally agreed that in most control programs, drift is an important variable in achieving the safe and efficient application of pesticides. Drift is influenced by air stability, wind, the type of application equipment, and the formulation of the chemical pesticide. Although there has been much useful research in the literature on the atmospheric transport of pesticide aerosols, or drift, as it is commonly called, there is a great need for a better distribution of this information accompanied by appropriately-timed agricultural weather advisories for the operational use of applicators and growers.

VII Agricultural Meteorology Summarization

Since the physical processes involving the influence of weather on chemical transformation, degradation, and removal are not as well understood as those involved in drift, research is greatly needed in connection with these atmospheric processes.

Another significant challenge to the meteorologist, the biologist and the pesticides chemical applicator is research on improved modification of the meteorological conditions of the pest microenvironment. It is expected that joining research by meteorologists, biologists, entomologists, chemists, scientists of other disciplines, engineers and applicators will provide the knowledge necessary to increase agricultural production and, at the same time, insure more intelligent use and better control to safeguard the environment, health and life span of both animals and man.

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